

ON THE INTERPRETATION OF THE ELECTROCARDIOGRAM.

BY W. A. JOLLY.

(From the Physiology Laboratory of the South African College,
Cape Town.)

(Read August 19, 1914.)

As was first shown by Waller,* the human electrocardiogram can be recorded by connecting the two hands or the hand and foot with the terminals of a capillary electrometer. Since the introduction of Einthoven's string galvanometer the electrocardiogram has become of great importance in the diagnosis of pathological conditions in the heart.

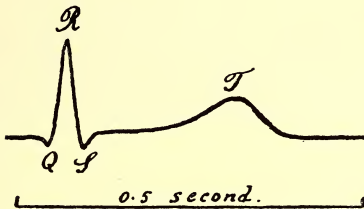


FIG. 1a.

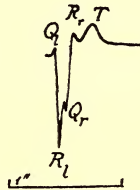


FIG. 1b.

The interpretation of the complex curve obtained has, however, remained obscure, and for its elucidation it is advisable to have recourse to experiments upon the simpler and more slowly acting hearts of cold-blooded animals, where it is possible to isolate a single chamber of the heart and to record the curves yielded by it when contracting either spontaneously or in response to artificial stimulation at one or other point of the musculature.

Fig. 1a gives the typical form of the ventricular electrocardiogram from

* Journ. of Physiol., vol. 8, p. 229, 1887.

the human being as figured by Einthoven.* In making this record the right electrode has been connected with the right hand of the subject and the left with the left foot. The summits of the curve are lettered *Q*, *R*, *S*, and *T*, by Einthoven.

It has been shown by several observers that similar curves can be obtained from the hearts of cold-blooded animals, and indeed from an isolated chamber of such a heart, and we may assume that there is a characteristic electrical expression for the activity of cardiac muscle generally. My experiments have been carried out upon the heart of the tortoise, removed from the body after killing the animal by decapitation.

The curve shown in Fig. 2 has been obtained in the following way: The heart of a large tortoise isolated from the body and continuing to beat

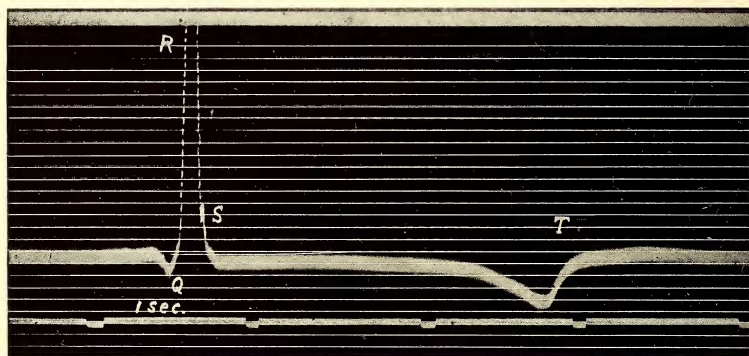


FIG. 2.

spontaneously was connected by two non-polarizable electrodes with the string galvanometer—Edelmann's large model of Einthoven's instrument. The right-hand electrode, which is connected with the lower end of the string of the galvanometer, and negativity of which, relative to the left-hand electrode, causes an ascent of the recorded curve, is applied on the ventral surface of the ventricle close to its right margin. The left-hand electrode, whose relative negativity depresses the curve, is applied to a corresponding point at the left margin.

Using the nomenclature introduced by Einthoven for the human electrocardiogram, this curve may be said to show in its ventricular portion an initial or *Q R S* complex, of which the summits *Q* and *R* are in

* Le télécardiogramme. *Archiv. internat. d. Physiol.*, 1906, iv., 132.

this case distinct. The breadth of the roll of sensitive paper on which the photographic record is taken is not sufficient to include the whole of deflection *R*. *S* does not appear in this curve as a distinct summit below the zero line, but there is an interruption on the descent of *R*. After the initial complex the record shows a horizontal stretch near the zero line, and terminates in the complex *T*, which here consists of a downward followed by an upward deflection.

In Fig. 3 the right-hand electrode has been applied to the auricles of an isolated spontaneously beating tortoise heart, and the left-hand electrode to the apex of the ventricle. The auricular part of the curve is seen to consist of an initial complex followed by a terminal slow deflection.

In Fig. 4 the right-hand electrode has been applied to the sinus of the

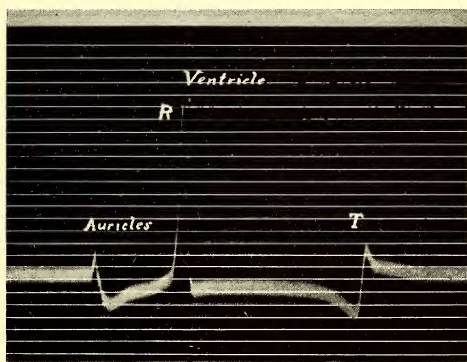


FIG. 3.

isolated spontaneously beating heart, and the left-hand electrode to the apex of the ventricle. The sinus part of the curve is seen to present an initial complex and a terminal slow deflection. The sensitiveness of the instrument is in this experiment too great to permit of the ventricular variation being recorded on the paper. It has been necessary to increase the sensitiveness in order to render the sinus variation evident. The rise *R* of the ventricular variation is seen following the auricular variation.

In the study of the electrocardiogram it is advisable to isolate one chamber of the heart, and I have chiefly directed my attention to the curve yielded by the quiescent ventricle when it contracts in response to artificial stimulation. The form of stimulus employed has been either a break induction shock or the mechanical stimulus of a touch by a glass

point. The point of stimulation and the position of the leads to the galvanometer have been varied.

Since electrodes connected with the two ends of the galvanometer string are applied at separate points of the heart muscle, we may take it that the curve obtained when the ventricle contracts, represents the algebraic sum of two similar electrical variations affecting the right- and left-hand electrodes respectively and therefore oppositely directed.

In order to throw light on such questions as where activity commences in the ventricle when spontaneously beating, and what path the excitation takes through the musculature, it is necessary to deduce from the curve the form of the electrical change which takes place under each electrode.

In a previous note* I have brought forward evidence derived from

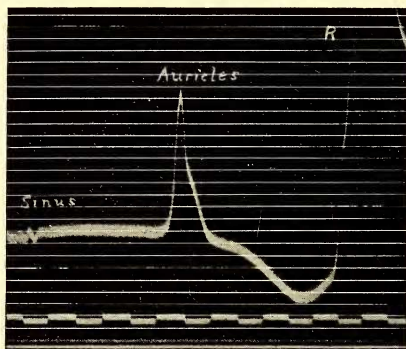


FIG. 4.

cases of systolic alternation in the tortoise ventricle, which would indicate that the electrical disturbance which accompanies activity in the tissue under one electrode when the wave of excitation is propagated to it, consists of a preliminary positive change, appearing as a descent of the curve, followed by a negative change shown by an ascent of the curve. The negative change after attaining its maximum shows a decline, which is later checked.

When large tortoise ventricles are available, and are stimulated artificially, it is possible to apply the electrodes at a considerable distance from each other, and as conduction of excitation is slow in the tortoise heart, the variation under one electrode may be distinctly seen to run its

* *These Transactions*, vol. iv., part i., p. 73, 1914.

course for a space in the record uncomplicated, before the other makes its appearance. Fig. 5 is an example. The stimulation is a break induction shock given through non-polarizable electrodes at the left margin of the isolated ventricle, and affecting the galvanometer string at x . The right electrode is placed on the dorsal surface about 6 mm. from the point of stimulation on the transverse diameter, and the left-hand electrode at the middle point of the dorsal surface 20 mm. from the right-hand electrode. From the peak lettered Q_r to Q_l the curve gives the variation under the right-hand electrode alone. At the beginning of the upward summit Q_l the variation under the left-hand electrode begins, and the remainder of the curve represents the summation of the two. It will be noticed that after deflection T the curve takes about 2 sec. to regain the zero line.

Fig. 6 gives a series of records from the isolated ventricle of the tortoise whose heart yielded the response in Fig. 2. The isolated quiescent ventricle was placed on a block of vulcanite and kept moist by Ringer's solution. Non-polarizable stimulating electrodes, connected with

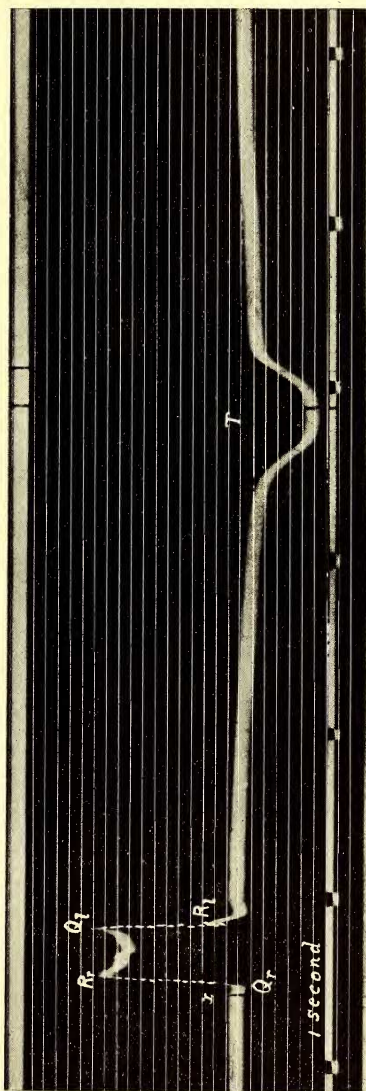


FIG. 5.

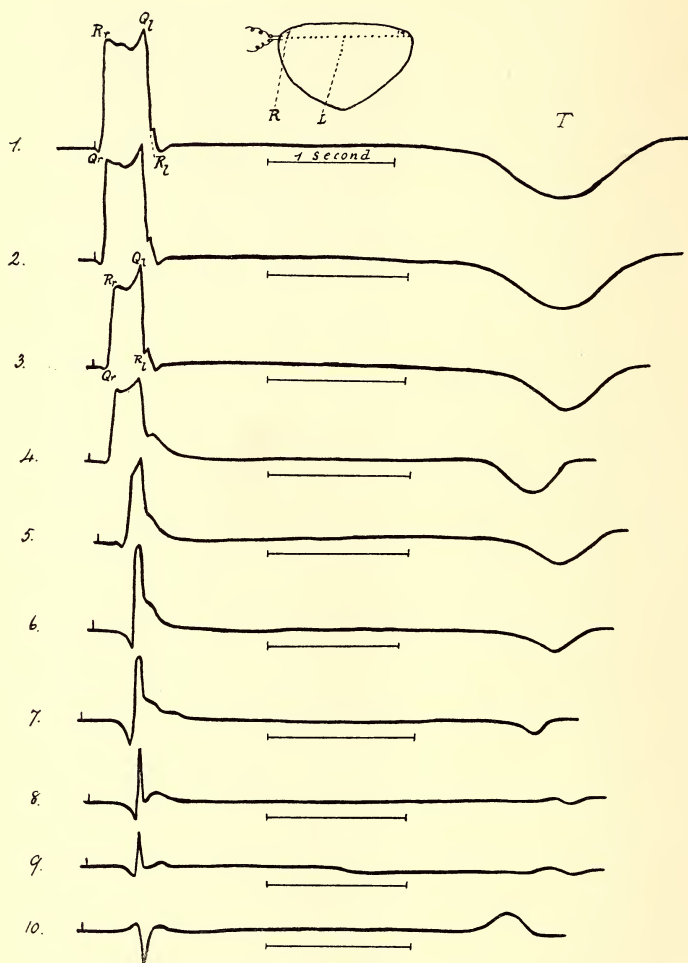


FIG. 6.

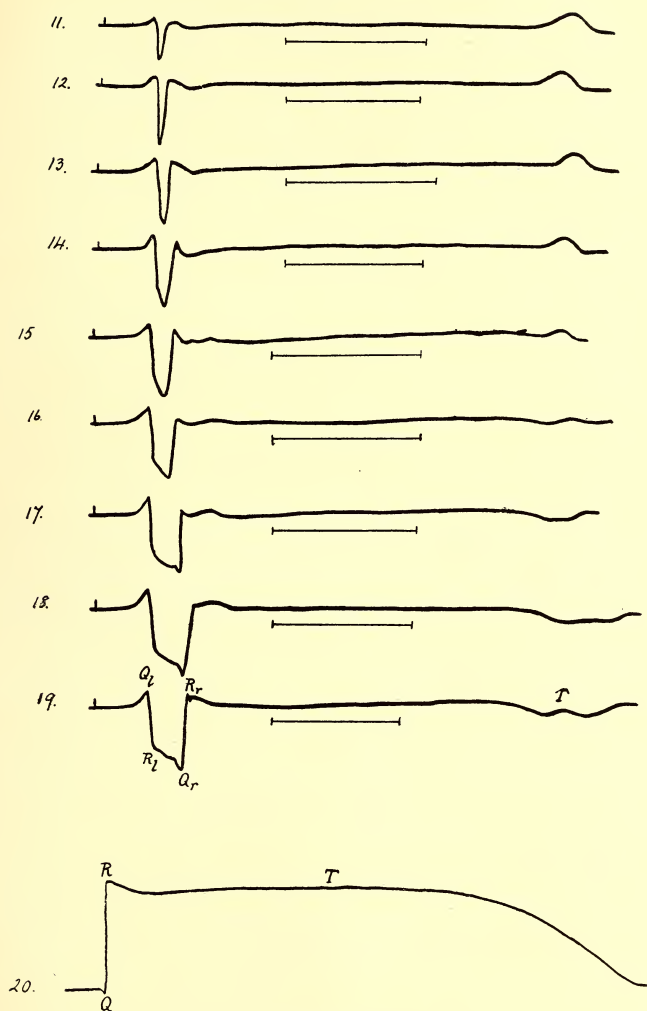


FIG. 6 (continued).

the secondary coil of an inductorium, were applied with their wicks about 2 mm. apart on the dorsal surface at the left lateral margin. The right and left leading off non-polarizable electrodes were placed, the left at the mid-point of the transverse diameter of the ventricle on the dorsal surface, where it remained during the experiment, and the right electrode was at first placed about 2.6 mm. from the point of stimulation on the line between that point and the left electrode, that is to say, on the transverse diameter of the ventricle. The right and left electrodes were 25 mm. apart. The ventricle was stimulated by a break induction shock, and the response recorded photographically on moving sensitized paper with a magnification of 660 diameters. The right electrode was then shifted by about 2.6 mm. along the transverse diameter towards the left electrode and another record taken, and the process was repeated, the right electrode being moved each time by as nearly as possible an equal distance towards the right margin, passing the left electrode at the middle point and being finally placed on the right margin at a point 50 mm. distant from its first position. In this way a series of records is obtained in which the variations under the right and left electrodes (what may be termed the right and left variations) are separated from each other by varying time intervals, the right variation at first leading, and after the crossing of the electrodes, the left variation leading.

Curve 1 commences with a downward deflection followed by an upward deflection. The curve then falls slightly and a plateau with small irregularities follows. The plateau is terminated by a sharp upward deflection, after which the curve falls to and beyond the zero line, being interrupted on its descent by a notch. After regaining the zero line the curve runs horizontally until it terminates in a slow descent and return. I have lettered the peaks Q_r , R_r , Q_l , R_l , and T . Q_r is the preliminary positive deflection of the right variation. R_r and the plateau indicates its succeeding negative portion. Q_l is the preliminary positive deflection of the left variation. R_l indicates the peak of its negative deflection, which is here followed by an increase of negativity giving the downward summit. The horizontal part of the curve is due to the compensation of the two variations, and the direction of variation T indicates that the right variation commences to decline before the left.

As the time interval between the variations is reduced the plateau shortens, and then the amplitude of the deflections is cut down. In curve 10 the left variation has begun to lead, and in record 19 we have a curve similar but of opposite direction to curve 1. As the variations change their time relations when the electrodes cross at the mid-point, the series of records shows that the terminal variation T changes from a downward to an upward deflection. In the later records this terminal variation is a complex presenting both downward and upward deflections.

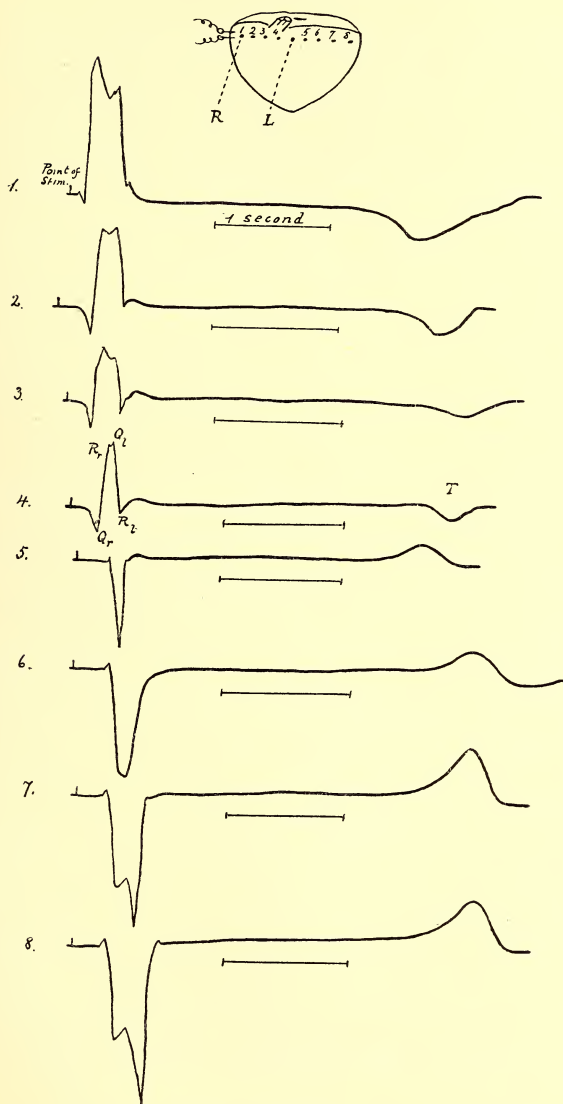


FIG. 7.

The curves in this series are explicable on the assumption that the two components have each a form similar to diagram 20 of Fig. 6, but may also present irregularities or oscillations, such, for example, that there may be a rise following *R* and exceeding it in height.

Fig. 7 gives a series of responses obtained from the ventral surface of the same ventricle. The stimulating electrodes are applied in this case at the right margin of the ventricle and the right electrode is placed first close to that point and then moved in successive steps along the transverse diameter to the left margin. The left electrode remains at the middle point. The reversal of *T* is well seen in this series as the variations change in time relations.

In Fig. 8 we have a series of records from the same ventricle with the following arrangement. The non-polarizable stimulating electrodes are applied at the left margin. The left leading-off electrode is at the right margin, and the right electrode is moved by successive steps from a position close to the point of stimulation towards the right margin.

In curve 1 *Q*, the positive deflection of the right variation is not evident. It is present in curve 2, and as the right electrode is removed farther from the point of stimulation this deflection increases in breadth and amplitude. It would appear that the positive change becomes more evident the farther the wave of excitation has to travel before reaching the proximal electrode, and it may be suggested that this is due to a difference in the rates of conduction of the positive and negative changes.

In Fig. 9 the records are obtained by placing the non-polarizable stimulating electrodes on the dorsal surface of the ventricle at the middle of the base and the left leading-off electrode on the dorsal surface at the apex. The distance between the point of stimulation and the left electrode is 34 mm. The right electrode is placed on the dorsal surface 2.6 mm. from the point of stimulation on the line joining the middle of the base with the apex. It is then shifted in successive steps of 2.6 mm. each towards the apex, and the response to a break induction shock is recorded at each position.

In Fig. 10 the stimulation is given on the dorsal surface at the apex, and the left electrode is placed at the middle of the base. The right electrode is applied 3 mm. from the point of stimulation on the line joining apex and base, and is then moved by successive steps of 3 mm. each towards the middle point of the base. It will be observed that in the earlier records of this series, where the right electrode is applied near the apex, the curve does not show a downward summit as its initial deflection, but the initial movement of the string is upward. As the right electrode is moved farther from the apex the summit *Q*, becomes evident, and in curve 7 it forms the initial deflection. This may be compared with responses obtained from other tortoise hearts. In Fig. 11 the non-polar-

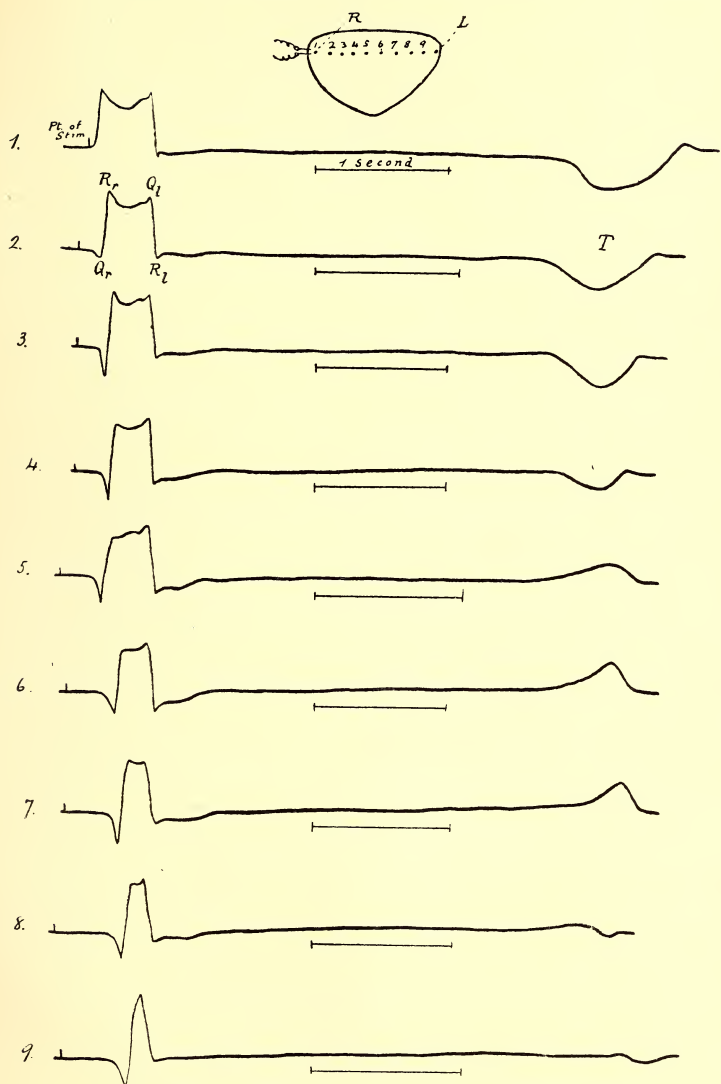


FIG. 8.

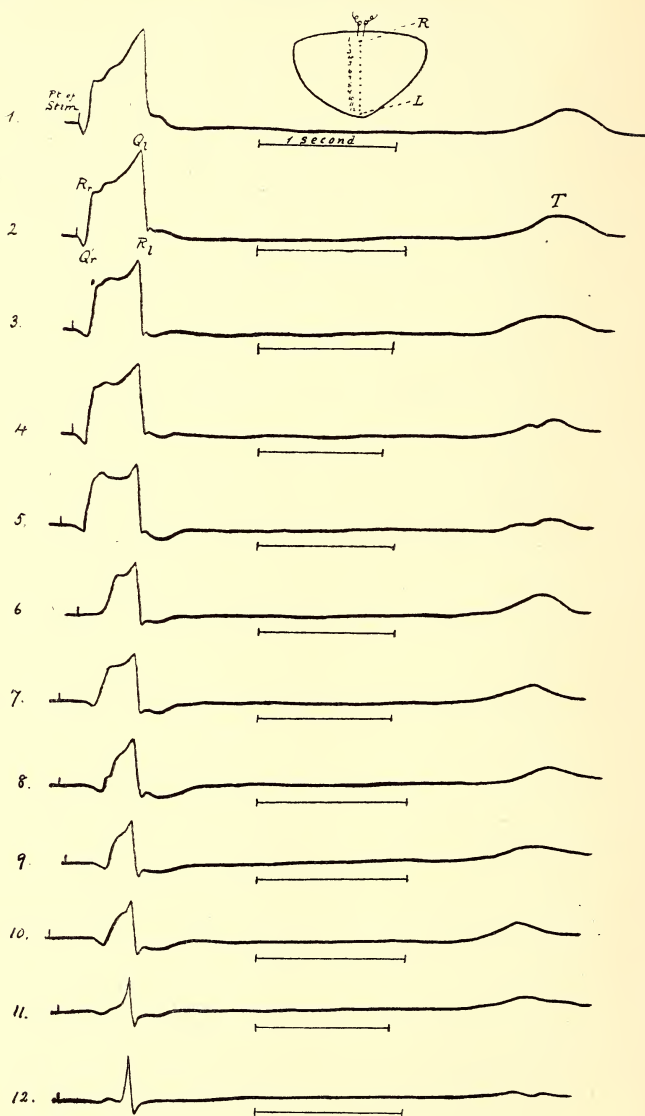


FIG. 9.

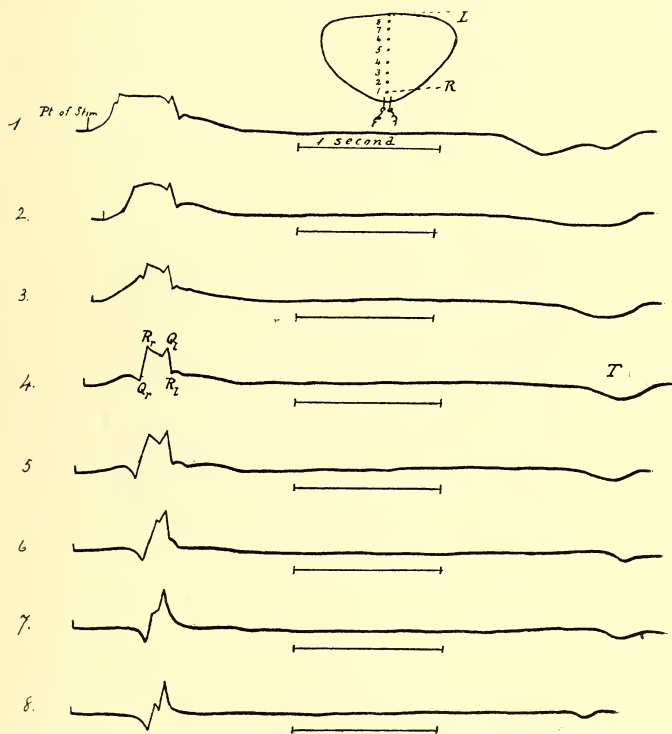


FIG. 10.

izable stimulating electrodes are applied on the ventral surface at the apex. The left electrode is placed on the ventral surface about 2 mm. from the point of stimulation, and the right electrode is applied to the mid-point of the base on the ventral surface. The break induction shock is evident on the curve, and the response appears to commence with the downward deflection, which indicates negativity of the left (here the proximal) electrode

In Fig. 12a both electrodes are applied close to the point of stimulation at the apex separated from each other by as short a distance as possible, and the stimulation is given mechanically by the touch of a glass point. The first movement of the string is a slight positive—upward—deflection preceding the downward deflection, which indicates negativity of the left

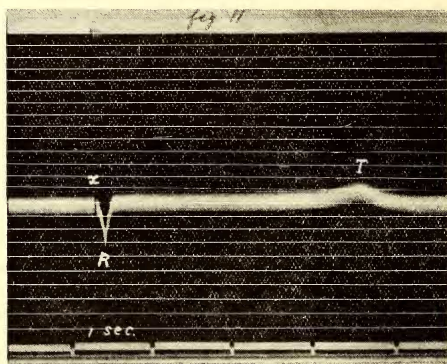


FIG. 11.

(here the proximal) electrode. In Fig. 12b the electrodes, retaining their relative position to one another, have been transferred to the middle of the base, and the apex is again stimulated mechanically. The positive deflection *Q* is here quite distinct.

In Fig. 13 we have a series of responses obtained from the isolated quiescent tortoise ventricle stimulated by break induction shocks when the application of the stimulus is transferred from point to point along the transverse diameter of the ventricle. The two leading-off electrodes are placed on the dorsal surface, the right at the left margin and the left at the right margin, separated from each other by a distance of 50 mm. The wicks of the non-polarizable stimulating electrodes are placed on the dorsal surface 5 mm. from the right electrode, and response 1 is recorded

to a break induction shock. The stimulating electrodes are then moved in successive steps towards the right margin along the line joining the two

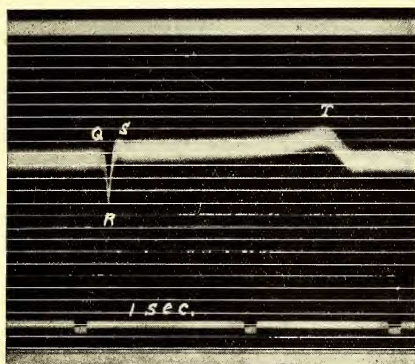


FIG. 12a.

leads, and the successive curves are obtained. In this way the right and left variations are in curve 1 separated by a time interval corresponding

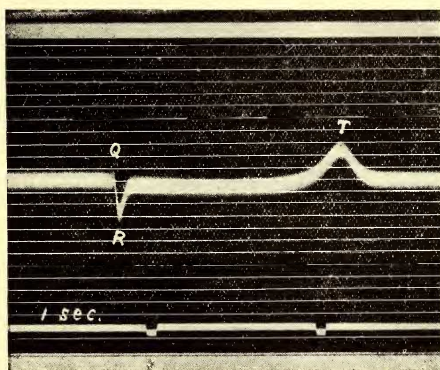


FIG. 12b.

to the conduction time of the excitation for a stretch of tissue of 40 mm., and the right variation is in advance of the left. In curve 4 the two varia-

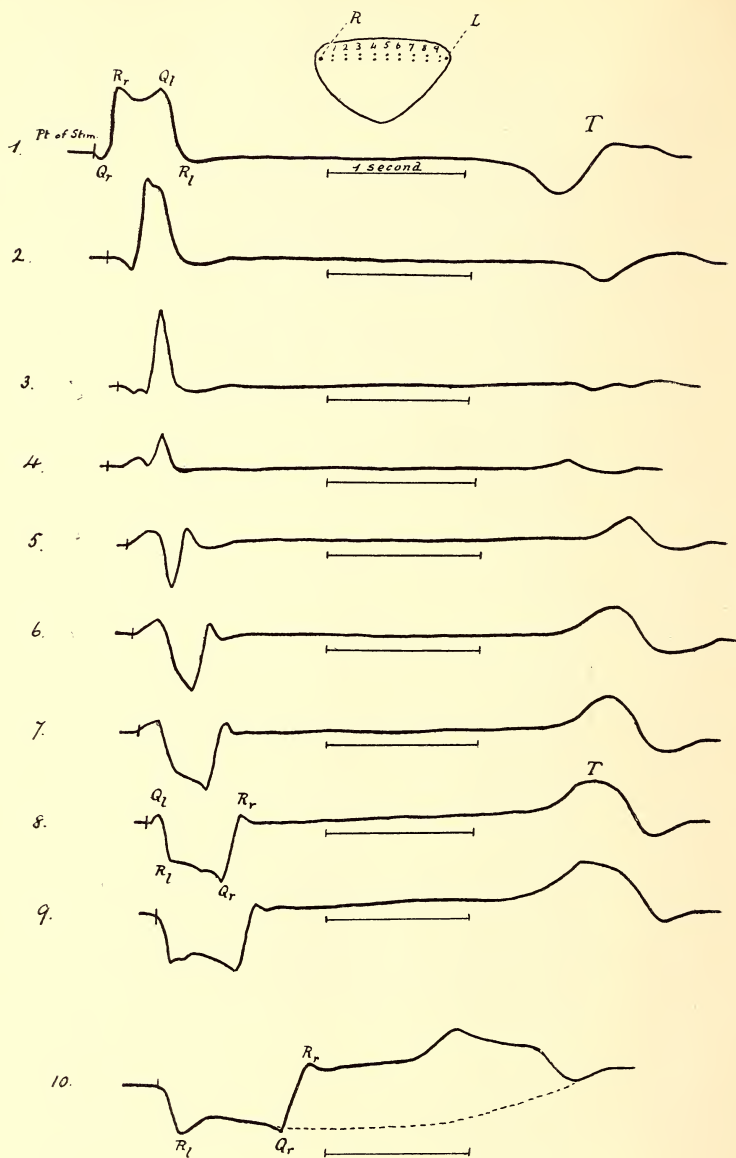


FIG. 13.

tions are elicited almost simultaneously, and in the succeeding curves again become more and more separate, the left variation in advance.

In curve 10 of Fig. 13, where the point of stimulation is close to the left electrode, the left variation leads and is recorded alone for about 0.75". The Q summit of the left variation is not evident. The right variation which commences at Q_r is short and can be distinctly seen superposed upon the left variation, whose supposed continuation is represented by the interrupted line.

The components of the electrocardiogram bear a close resemblance to the electrical variation recorded from the eye on stimulation by a flash of light. In Fig. 14 an example of a retinal variation is reproduced.*

Fig. 15 gives a series of curves obtained from an isolated tortoise ventricle. The non-polarizable stimulating electrodes are applied on the ventral surface at the left margin, the right leading-off electrode on the transverse diameter 2 mm. to the left of the point of stimulation and the left electrode at the right margin. The right electrode is moved in

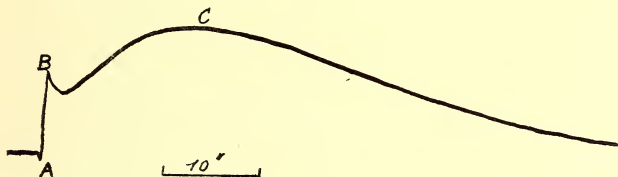


FIG. 14.

successive steps of 2 mm. each towards the left electrode, and the response to a break induction shock recorded at each position.

Fig. 16 gives a series of responses from the same tortoise ventricle obtained by stimulating the dorsal surface mechanically at the left margin by the touch of a glass point. The left electrode is placed on the dorsal surface at the right margin. The right electrode is at first applied about 2 mm. from the point of stimulation at the left margin, and is then moved in successive steps of about 3 mm. each along the transverse diameter towards the right margin.

From the results obtained from the isolated tortoise ventricle where I have found the rate of conduction to artificial stimulation to be from 9 to 11 cm. per sec., it is I think possible to analyse the human electrocardiogram given in Fig. 1. It represents the summed effect of two variations, that is to say, of (1) the changes occurring on activity in the tissue whose potential is communicated to the right electrode at the right hand of the subject—

* Einthoven and Jolly, *Quart. Jour. of Exper. Physiol.*, vol. i, p. 373, 1908.

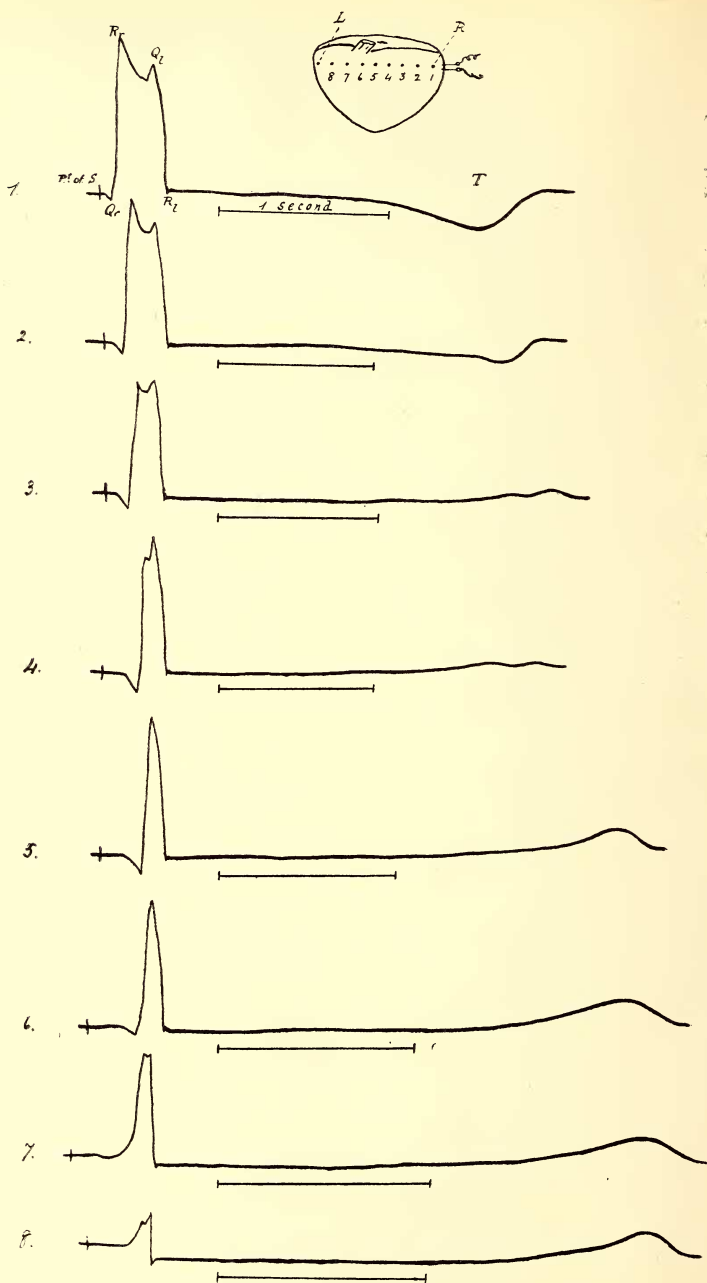


FIG. 15.

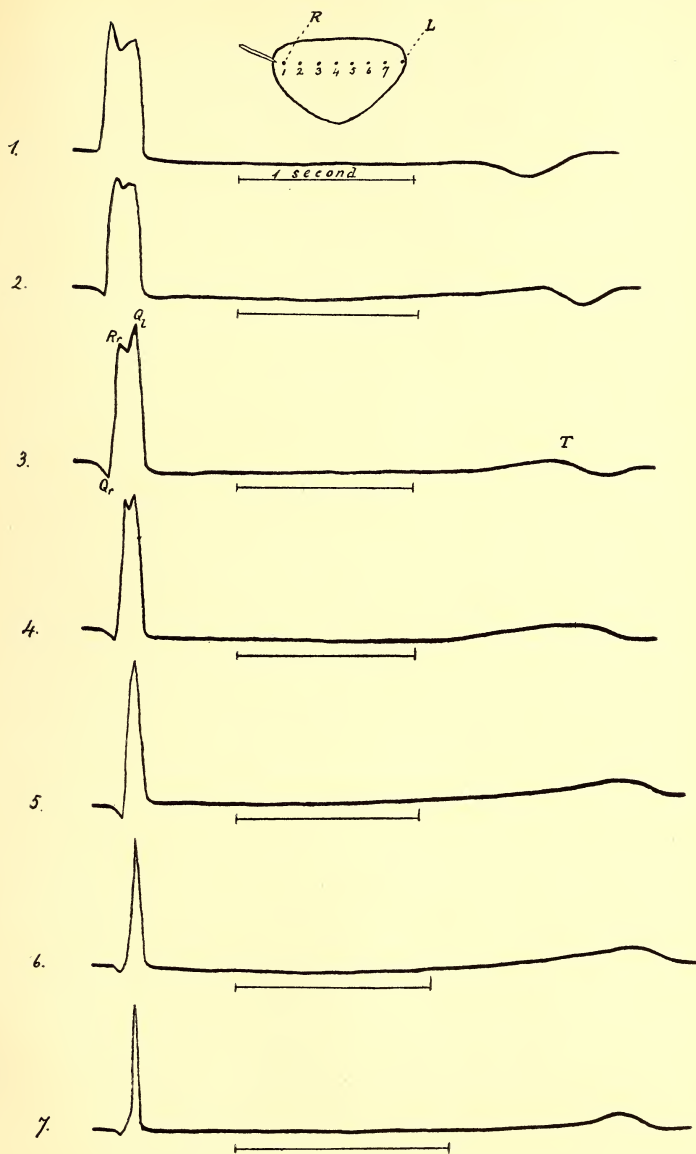


FIG. 16.

the right variation, and (2) the changes in the tissue whose potential is that of the left electrode, connected with the left foot of the subject—the left variation. Each variation commences with a positive deflection succeeded by a negative deflection. The downward direction of the summit Q of Einthoven is to be attributed to the positive preliminary deflection of the right variation— Q_r in my nomenclature; and is due to the commencing electrical change in the tissue at the base and right side of the ventricles. R is the combined effect of the negative deflection of the right variation and the positive preliminary deflection of the left variation ($R_r + Q_l$). S is the summit of the negative deflection of the left variation (R_l) due to negative electrical change at the apex and left side of the ventricles. The horizontal stretch following S indicates compensation of the two variations, and T is due to the right variation, which persists longer or passes off less steeply than the left variation.

In comparing the forms of the human electrocardiogram with the curves in Fig. 13, it is evident that the point at which the excitation transmitted from the auricles reaches the general ventricular musculature would correspond to the point of artificial stimulation of the isolated tortoise ventricle.* The position of this point relative to the right and left lead respectively will thus determine the form of the electrocardiogram, since it will determine the time relations of the two variations which are summed. The human electrocardiogram is not always of the same form even in normal individuals, and varies very greatly under pathological conditions. The form of the typical normal curve indicates that the two variations or phases are occurring almost simultaneously, but with the right variation slightly before the left. We would therefore conclude that the excitation reaches the ventricular musculature almost at the middle point but slightly nearer the base. Atypical curves will be recorded when the excitation begins in the ventricles at an abnormal point, and the two phases will be separated by a greater time interval.

I do not propose to discuss here the various forms of the pathological electrocardiogram. A very large number of atypical curves have been recorded in the literature. In Fig. 1*b* there is an atypical curve from a human electrocardiogram which I have recently recorded in this Laboratory, in which it seems possible to make out the various summits that can be identified in the tortoise response. The curve has been recorded by derivation II, that is to say the right electrode is connected with the right hand, the left with the left foot. The left variation or phase is an advance of the right, which indicates that the excitation has begun in the ventricular muscle at a point nearer the apex than in the normal case.

* Cf. Einthoven, *Pflüger's Archiv.*, Bd. 149, s. 65, 1912.